THE CHALLENGE OF A DESERT: REVEGETATION OF DISTURBED DESERT LANDS[1]

A. Wallace[2], E. M. Romney[2], and R. B. Hunter[2]

ABSTRACT.— The revegetation of disturbed, arid lands is one of the great challenges of a desert. An attempt to encourage it is not an impossible task, however, if the natural and the man-made resources available are utilized and managed. Where rainfall and temperature conditions approach or exceed those of the Great Basin desert, restoration of disturbed land will occur through natural revegetation processes within a reasonable period of time. This is not generally the case in the more arid Mojave Desert areas where the moisture and temperature conditions are less favorable for germination and seedling survival. Restoration of vegetation by natural reseeding can, however, occur within local sites where moisture has concentrated as the result of terrain features forming catchment basins. Otherwise, the natural revegetation processes in the Mojave Desert areas require much longer periods of time (possibly decades or centuries) than are practical for meeting environmental protection standards imposed by current legislation.

Through better understanding of the processes governing revegetation and the ability to control them, it is possible for man to more rapidly restore disturbed desert lands. Terrain manipulation to form moisture catchment basins, selection of seed from pioneering shrub species, preservation of existing shrub clump "fertile islands" in the soil, supplemental fertilization, irrigation, organic amendments, and transplanting vigorous shrub species are some of the important things that can be done to help restore disturbed desert land.

With current stress on maintenance of the quality of the environment and with responsibility for its status placed upon those using a given area, it is increasingly important that we who are involved understand many aspects of the ecosystem in which we work. The facts that deserts are very fragile and that efforts to restore them after disturbance can lead to frustration and failure are well known. We are proceeding in our work with the assumption that our ability to control the factors related to restoration of deserts, whenever the need arises, is proportional to how well we understand the processes governing germination and survival of desert plants. In this report we describe some aspects of natural processes that are of great importance to revegetation problems in the northern Mojave and southern Great Basin deserts (Beatley 1965, Wallace and Romney 1972, 1974, 1976).

SYNOPSIS AND DISCUSSION OF EXPERIMENTAL FINDINGS

A listing and description of some of the more important behavioral aspects of the deserts in which we work are given below. Details of experiments from which some of the findings were obtained have been previously published (Wallace and Romney 1972, Romney et al. 1973, Romney et al. 1974, Hunter et al. 1975, 1975a, Romney et al. 1977a). The work of Beatley contributes considerably to an understanding of plants under the desert conditions involved in these studies (Beatley 1965, 1965a, 1965b, 1965c, 1966, 1967, 1973, 1974, 1974a, 1975, 1976).

1. Water is the most important parameter governing biological responses in the desert ecosystem; however, equal quantities of water via natural precipitation do not always result in equal responses. Some of the factors

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[1] Modified from DOE Report NVO-181, 1978.

[2] Laboratory of Nuclear Medicine and Radiation Biology, University of California, Los Angeles, California 90024.

involved include: (a) rainfall during time when high temperatures cause heavy loss through evaporation, (b) rainfall during the time when plants are in a physiological state of low temperature or high temperature dormancy, (c) high intensity rainfall where loss by runoff is considerable, and (d) cool, spring temperatures that decrease evaporation, enabling a greater proportion of the soil moisture to be used in transpiration.

Because the small amount of precipitation falling upon the northern Mojave Desert (10 to 15 cm per year) varies both in amount and time of distribution (Table 1), and because seasonal temperatures vary consistently during the plant growing season, no two years are really alike. Such has been the case for more than the decade during which we have collected environmental information at the Nevada Test Site. This means that it is not only difficult to predict results, but also that new plant survival is precarious even when transplanted ones are irrigated during the first summer season. A generalized description of why there is year-to-year variation in the biology of the northern Mojave Desert is given in Table 2.

2. Vegetation of the northern Mojave Desert really uses only about 10 to 20 percent of the soil area as a growth medium and the other 80 to 90 percent is used largely as a watershed. This results in the familiar shrub clump or "fertile island" structure characteristic of some deserts (Charley 1972, Charley and West 1975, Romney et al. 1973, Romney et al. 1977a, 1977b). These shrub clump sites have probably been in place for centuries (Wallace and Romney 1972) and are just as structured and fertile as soil in more humid ecosystems (Roberts 1950, Paulsen 1953, Charley and Cowling 1968, Rickard 1965, Garcia-Moya and McKell 1970, Tiedeman and Klemmedson 1973). This means that the water coming into the system is used with the energy of photosynthesis, through decomposition, to maintain just a fraction of the total soil area as highly productive sites. The remainder of the soil serves as needed watershed, and it usually contains some roots. When this soil structure involved with shrub clumps is destroyed mechanically by bulldozers, graders, etc., centuries of the results of biological cycling is destroyed and, by itself, such a damaged desert ecosystem will recover very slowly.

Soil organic matter levels are reasonably high in the shrub clump areas and usually very low in the intervening bare soil areas (Charley 1972, Romney et al. 1973, Romney et al. 1977). Soil organic matter at a given temperature decreases with decreasing rainfall (Jenny et al. 1949). As the climatic conditions of the northern Mojave and other deserts are encountered, upon comparing conditions varying from humid to arid, as in Figure 1, the soil organic matter level does not decrease within the shrub clump sites as it does in the rest of the desert soil area. The generalized curve of that relationship between soil organic matter and precipitation is, therefore, distorted within the range for desert conditions, as illustrated in Figure 1. This structuring of the soil surface into highly productive and poorly productive areas is of utmost importance to the maintenance of the Mojave Desert type of ecosystem.

3. The plant size structure of the perennial plant population of the northern Mojave Desert indicates a reasonably active system in which new individuals constantly enter the ecosystem (Hunter et al. 1975b, El-Ghonemy et al. 1980a, b, this volume). New individuals usually do not enter the system each year, however. Instead, they enter mostly during those years in which rainfall is sufficient for germination and seedling survival. Precipitation records (Table 1) indicate that the above-average rainfall during the winter periods of 1968–1969 and 1972–1973 possibly explains the apparent "pulse" input of new seedlings of certain shrub species (Romney et al. 1980, this volume). The information that only two years out of six were conducive to

TABLE 1. Annual precipitation during period of 1 July to 30 June, Rock Valley, Nevada.[1]

Year	mm	Year	mm
1963–1964	100.7	1970–1971	98.9
1964–1965	121.2	1971–1972	91.7
1965–1966	163.4	1972–1973	275.7
1966–1967	100.9	1973–1974	76.2
1967–1968	153.6	1974–1975	138.4
1968–1969	279.7	1975–1976	61.4
1969–1970	89.6		

[1] Air Resources Laboratory, NOAA, Las Vegas.

new seedling establishment at Rock Valley, Nevada, is important to an understanding of the difficulties one encounters in attempting to restore desert lands without the benefit of supplemental water.

4. New perennial plant seedlings are more apt to become established within the fertile shrub clump areas rather than in the bare spaces between them. Fortunately, however, there are several pioneer species in the northern Mojave Desert that can grow under the hostile environment of disturbed soil, and even in subsoil that is very low in organic matter. El-Ghonemy et al. (1980b, this volume) concluded that the commonly occurring *Atriplex confertifolia* is an important pioneer species useful in the restoration of disturbed desert land.

5. An established shrub population effectively controls germination and survival of new perennial plants by controlling soil moisture. There are two important consequences to consider regarding maintenance and restoration of disturbed lands. One is that as long as the established plants are in place there will be relatively little input of new perennial plants. Establishment of new plants largely depends upon replacement of dying individuals over a relatively long period of time. The second is that destruction of the existing population will so change the soil moisture status that many new plants will become established initially, after which time competition culls out the weaker seedlings and a steady state population once again is established.

In areas having greater than 15 cm annual rainfall, it is highly probable that the new vegetation restored on disturbed land initially

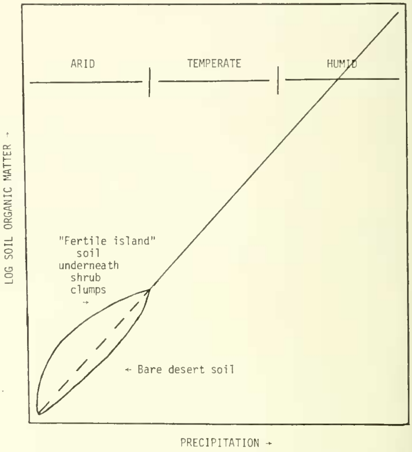

Fig. 1. Hypothetical relationship between soil organic matter content and precipitation. Centuries of biotic activity and recycling and concentration processes have developed the fertility of the soil underneath shrub clumps to levels comparable to soil formed under more humid conditions.

Table 2. An example of the annual productivity options for shrubs in the northern Mojave Desert with constant rainfall (10 cm/yr), but with variable time of input and with variable mean seasonal temperatures.

Major seasonal rainfall period			Air and soil temperatures		Estimate of shrub productivity ± 25 percent	
Nov–Dec	Jan–Feb	Mar–Apr	Jan–Feb	Mar–Apr	kg/ha	Percent
E	–	–	C	C	600	200
E	–	–	W	W	300	100
E	–	–	W	C	400	133
E	–	–	C	W	500	167
–	M	–	C	C	800	267
–	M	–	W	W	400	133
–	M	–	W	C	500	167
–	M	–	C	W	600	200
–	–	L	C	C	800	267
–	–	L	W	W	500	167
–	–	L	W	C	600	200
–	–	L	C	W	700	233

E = early season, M = mid-season, L = late season, C = cold, W = warm. Other options than above would occur from different combinations of rainfall input and variable temperatures. Above data indicate differences as great as 267 percent could occur with same rainfall and same evapotranspiration if no runoff or leaching below root zone occurred.

will be a grassland type instead of a reproduction of the original shrub. Range management skills have been developed to improve the grazing potential of rangelands because of this condition, as is commonly done on Great Basin desert lands (Plummer et al. 1955, 1968). Seed availability is a limiting factor in the process, so an artificial seeding of appropriate grass species in disturbed areas generally is done to create a more successful grazing area. One thing that must be taken into account, however, is the likelihood that newly disturbed Great Basin desert areas will become invaded by *Salsola* species (Russian thistle), unless control measures are taken.

6. Inasmuch as soil moisture controls germination of new seedlings to a large measure, the process can be controlled effectively by manipulation of surface terrain to facilitate the concentration of precipitation runoff into catchment basins. These principles have been worked out in desert areas by Evanari et al. (1971). We have emphasized this point in our past discussions on feasibility of cleaning up contaminated desert land (Wallace and Romney 1974, 1976).

7. Animals control seedling survival to a great extent (Plummer 1955, Plummer et al. 1968, Wallace and Romney 1972, 1974, 1976). Not only do rabbits prune plants aboveground, but pocket gophers also destroy plants by eating roots. Even with wire screens to help exclude animals from new shrub transplants, they still have noticeable effects (Hunter et al. 1980, this volume).

Animals also have some positive effects in that they aid in the decomposition and nutrient cycling process. Some species help to conserve the small amount of fixed nitrogen in the system by moving litter underground. Animal activity helps to maintain the shrub clump areas as fertile zones within the ecosystem.

8. The availability of combined forms of nitrogen is vital to an ecosystem. Any disturbance that destroys the fertile shrub clump islands and topsoil of deserts imposes a very severe limiting factor on restoration of vegetation on that land. Biological fixation of nitrogen is very precarious under desert conditions (Hunter et al. 1975a, Wallace et al. 1977). However, a very conservative mechanism results in the presence of sufficient nitrogen to maintain the amount of vegetation made possible by the rainfall. Any attempts at restoration of disturbed sites must consider the nitrogen needs. Fortunately, this may be achievable with fertilizer amendments applied to replace, or supplement, that nitrogen which would be lost to the system by site disturbance of the kind that would occur from cleanup activities (Wallace et al. 1977).

9. Species of vegetation that dominate the northern Mojave Desert have either a low leaf water potential (like *Larrea tridentata* Sess & Moc. ex DC.) Cov. and *Krameria parvifolia* Benth.) or else they are adapted to complete a life cycle during the relatively cool, moist season of the year, followed by dormancy during the hot, dry periods [like *Ambrosia dumosa* (A. Gray) Payne, *Grayia spinosa* (Hook.) Moq., and *Lycium andersonii* A. Gray]. Two of this last group do not go into dormancy when irrigated during the hot period of the year, but *Grayia spinosa* does (Wallace et al. 1970, Wallace and Romney 1972). Revegetation procedures using transplants of rooted cuttings of deciduous shrubs must take into account the dormancy behavior of each species. Transplants that are dormant during the hot, dry season are best maintained that way rather than attempting to force them to break dormancy and undergo new vegetative growth out of season. Rooted cuttings from a number of Mojave Desert shrub species can be used for transplanting stock, especially if planting time can be arranged during the late fall or early spring months when seasonal moisture is most favorable (Wieland et al. 1971).

10. Response of vegetation to water in the northern Mojave Desert is rather complex, the result of several interacting factors. Among the more obvious aspects of water is timing, which itself can be rate limiting. Water can be of relatively little value if it is supplied at a time when it will be lost by evaporation or during a phenological stage of development when no response can be expected. During most early spring seasons in the northern Mojave Desert, there are periods when water is not limiting to plants. Soil moisture from winter rainfall is present, but the period of plentiful supply will depend upon the recharge supply for that year and

upon the temperature conditions that determine how fast the plants use the available water supply.

Response to supplemental irrigation, therefore, is not always a simple, predictable matter, yet some extremes in shrub responses have been documented (Romney et al. 1974, Hunter et al. 1975a). If winter rainfall has been sparse, the response of some shrub species can be dramatic when irrigated during the spring growth season. If, however, the soil moisture recharge level is high from heavy winter rainfall, the supplemental irrigation may do nothing more than help extend the growth period until the soil eventually dries out. This extension of normal growth period by relieving water stress can increase the biomass production of some shrub species severalfold, but other plants cannot respond as much because of slow growth patterns imposed by their genetic nature. If additional water is to give further yield increase, the species in a community must be changed to the kinds of plants that respond more to water. This is why extra water tends to change desert areas into grasslands (Wallace and Romney 1972).

Under desert ecosystem conditions, a given amount of water will sustain a given amount of primary productivity. If the amount of water were increased to a higher level and maintained year after year, the system would adjust to the new level with a new productivity plateau (Fig. 2). Water could again become the rate-limiting factor for this new growth plateau, but it also could be nitrogen or some other nutrient. It could even be genetic so that no additional productivity could occur even with input of more water and nutrients. This barrier may be overcome with increased density of species, but additional nitrogen would also have to become available to sustain that added productivity. Eventually another plateau would be reached following a somewhat hypothetical series of changes as illustrated in Figure 2. Supplemental nitrogen may not be necessary until the second- or third-stage limiting zones are reached, providing the nitrogen fixation and nutrient cycling processes are not overstressed until then. With time it can be expected that an equilibrium would be reached where nitrogen fixation could supply any new needed nitrogen to maintain either of the two higher plateaus, if the nitrogen present were permitted to cycle within the system (Day et al. 1975). The relationship among plant species, water supply, and available nitrogen supply must be understood for a given system if these factors are being manipulated in revegetation work.

Reasonable survival of transplanted shrubs occurred in some small field plot experiments where the effectiveness of protecting new transplants from grazing rabbits by wire screens was demonstrated (Table 3). In addition, the new transplants received periodic irrigation during the late spring and summer months after planting. Results indicate that several shrub species can be used effectively to restore vegetation on disturbed Mojave Desert land with reasonably inexpensive husbandry procedures.

11. The parasitic plant (*Cuscuta nevadensis*) Jtn (dodder) can regulate survival of perennial plants in the desert (Wallace et al. 1980, this volume). Its presence generally is not widespread over large areas, but it may concentrate heavily in specific localities having ideal environmental conditions for its growth. Especially during cool, moist springtime weather, this plant can infest and kill a number of perennial species. We have observed its effects on *Ambrosia dumosa* (A. Gray) Payne, *Acamptopappus shockleyi* A. Gray, *Atriplex canescens* (Pursh) Nutt., *A. confertifolia*, *Ceratoides lanata* (Pursh) J. T. Howell, *Coleogyne ramosissima* Torr., *Encelia virginensis* A. Nels., *Grayia spinosa* (Hook.) Moq., *Hymenoclea salsola* Torr. and Gray, *Lycium andersonii* A. Gray, *L. pallidum*, *Mirabilis pudica* Barneby, *Prosopis juliflora* (Sw.) DC., var. *torreyana*, and *Psorothamnus fremontii* (Torr.) Barneby. Dodder probably infests many other plant species in the Mojave Desert. Beatley (1976) identified five different species of *Cuscuta* active in the central-southern Nevada area.

12. Many desert plant species exist as local ecotypes highly adapted to the local climatic and edaphic environment (Plummer et al. 1955, 1968). Unless plant material used for revegetation of a given site comes from that site (i.e., seed or stock for making transplants), difficulties may be encountered in restoration of the site.

TABLE 3. Percent survival of transplanted shrubs, Nevada Test Site, 1976.°

	W. Frenchman Flat		N. Frenchman Flat		Yucca Flat	
Plant species	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced
Ambrosia dumosa	50(6)°°	50(10)	0(3)	50(4)	—	—
Atriplex canescens	33(6)	0(10)	100(3)	83(4)	60(5)	0(60)
Artemisia tridentata	—	—	100(3)	17(4)	100(7)	90(30)
Artemisia ludoviciana	—	—	—	—	75(4)	55(9)
Ceratoides lanata	0(6)	0(10)	67(3)	0(4)	20(5)	0(5)
Chrysthamnus nauseosus	—	—	—	—	33(3)	33(3)
Grayia spinescens	—	—	—	—	60(5)	8(12)
Larrea tridentata	50(6)	60(10)	100(3)	67(4)	—	—
Lycium andersonii	33(6)	10(10)	—	—	0(3)	33(3)
Yucca brevifolia	—	—	—	—	28(7)	44(9)
Yucca schidigera	67(8)	0(10)	67(3)	17(4)	—	—

°W. Frenchman transplanted 2/20/72; N. Frenchman 2/16/73; Yucca Flat 12/18/71.

°°Values in parentheses indicate number of specimens transplanted with or without protective wire enclosures. Shrubs were watered upon demand during the first six months after transplanting.

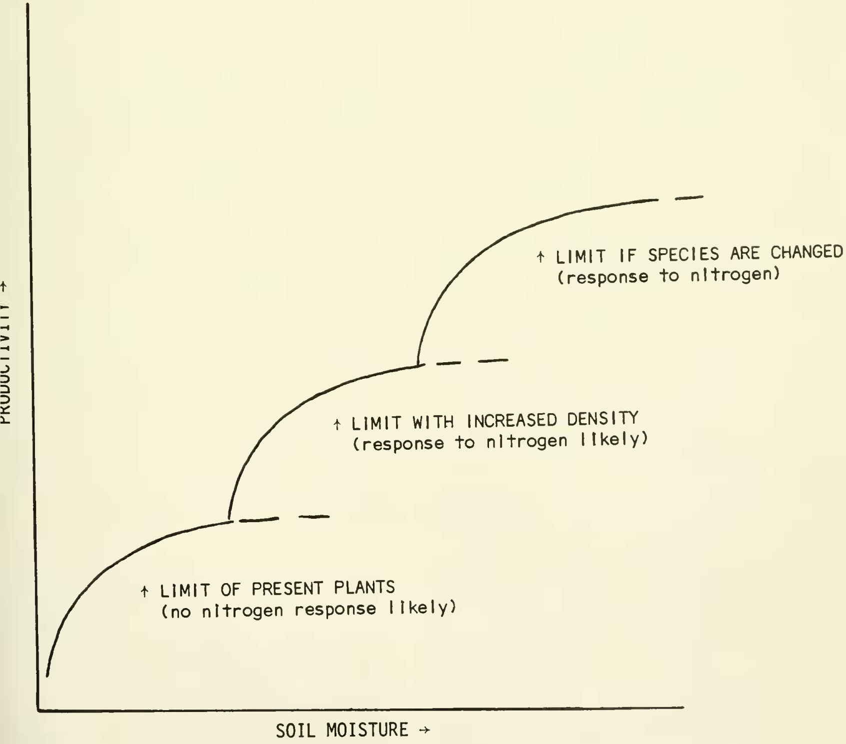

Fig. 2. Hypothetical response of desert vegetation to supplemental moisture. Advancement to the second and third productivity plateau requires successive change in density of species and change of population to more efficient plant species (Romney et al. 1977b).

13. Revegetation of disturbed areas under natural, unmanipulated conditions is more complete and faster in areas having higher rainfall and lower mean temperatures. As one goes from the northern Mojave to the southern Great Basin desert (i.e., southern to northern areas of the Nevada Test Site), changes in climate such as this occur. The Great Basin areas reestablish themselves much faster than those in the Mojave Desert when disturbed. This results primarily from the greater seed germination and seedling survival under higher rainfall conditions.

Several sites were mechanically disturbed in the Great Basin part of the Nevada Test Site during nuclear testing activities in 1957 (Dick and Baker 1969). The condition of these study sites has been examined periodically to follow the natural revegetation processes underway. In May 1976, the following annual plant count was made on 10 × 10 m plots: 450 in plowed site, 13 in scraped site, 168 in disked site, 250 in control site. The high variability in annual plant distribution observed in the general locale for 1976 would indicate no effects of the plowed or disked treatments compared to undisturbed areas. There still remained, however, some indications that earlier removal of topsoil from the scraped site caused reduction of annual plant populations. Data in Table 4 indicate the extent of shrub restoration on these disturbed sites compared to the undisturbed control area. These data are estimates obtained from nondestructive, dimensional measurements of shrubs and grasses growing in the study sites. The methods of analysis and some other examples of results obtained by those methods elsewhere have already been reported (Wallace and Romney 1972, Romney et al. 1973, 1974). Represented among the species included in these estimates are *A. canescens*, *A. confertifolia*, *Artemisia spinescens* D. C. Eat., *C. lanata*, *Chrysothamnus viscidiflorus* (Hook.) Nutt., *Oryzopsis hymenoides* (Roem. & Schult.) Ricker, *Sitanion jubatum* J. G. Sm., and *Sphaeralcea ambigua* A. Gray. Excellent natural recovery has occurred in these disturbed areas through reseeding from species growing in the adjacent area during the 18-year period following the initial disturbance. The plowed and disked plots now show about one-third recovery compared to normal, but the plot having had the top soil scraped from it shows about one-fifth of normal.

14. Nuclear testing activities have in some cases destroyed the natural vegetation in local fallout areas by heat and blast damage and by radiation, or through mechanical damage from site preparation. These disturbed fallout areas have been useful for studying natural restoration of vegetation.

Artemisia is the dominant genus of plants growing in the southern Great Basin desert of the Nevada Test Site (Beatley 1976). We have had occasion to study its behavior for more than a decade following some of the nuclear test events (Wallace and Romney 1972, Romney et al. 1971). As mentioned above, sufficient data have been obtained to substantiate that the pulse hypothesis occurs for the establishment of new *Artemisia* plants (Romney et al. 1980, this volume). New shrub seedlings may have germinated from seed deposited earlier in the area before the disturbance occurred or from seed dispersed from adjacent undisturbed areas. The main trend of succession in the restoration of vegetation in these disturbed sites has been a heavy influx of *Salsola* species during the first three years after disturbance, followed by a steady conversion to grasses. Even though new shrub seedlings have become well established in numbers during the first decade of time, the disturbed sites now give the appearance of having been restored to grassland. This, of course, eventually will change as competition from developing shrubs forces out the newly introduced grasses.

Table 5 contains data taken from two study plots located within one of the damaged fallout areas and from a nearby control

TABLE 4. Natural recovery of vegetation on disturbed soil in Area 13, Nevada Test Site (soil was disturbed in 1957).

Kind of soil disturbance	Condition of perennial plants, 1976[a]		
	No./ha	% cover	kg/ha
Undisturbed	12,000	27.6	3,200
Plowed	9,000	9.7	1,185
Disked	9,300	10.5	1,233
Scraped	6,000	4.8	653

[a] Estimates made by nondestructive, dimensional measurements (Wallace and Romney 1972).

area. Sites were selected within areas where vegetation had been totally killed, partially killed, and undisturbed by radiation from fallout debris (Rhoads et al. 1969, Romney et al. 1971). Rainfall conditions varied considerably from year to year during the decade of time in which periodic observations were made (approximately like those in Table 1). As the result, many new seedlings would have germinated and subsequently died during wet and dry periods between the years when plot inventories were made. The results in Table 5 indicate a reasonably stable condition of seedling establishment in the control area populated with about 1000 mature, live *Artemisia* shrubs. Approximately the same numbers of shrubs had been growing on the disturbed plots as on the control plot, based upon shrub carcass counts. Seedling restoration has appeared to be more rapid on the partially killed plot than on the totally killed plot, but in either case the numbers that have germinated and survived are sufficient to eventually restore the disturbed fallout area to its original condition. The numbers of grasses on the disturbed plots indicate the succession trend to grassland compared to the undisturbed area. The density of *Ceratoides lanata*, *Chrysothamnus* spp., and *Tetradymia axillaris* seedlings was much higher on the disturbed plots than normally occurs in the adjacent, undisturbed area. The invasion and establishment of these species from external seed sources probably was made possible by the more favorable moisture conditions in areas where the competitive *Artemisia* shrubs had been destroyed. An interesting, rather complex trend of shrub species succession should occur in this disturbed fallout area between now and the time it passes through the grassland and shrub complex phases back to its original condition. The most important point in Table 5 is that disturbed sites in the Great Basin desert areas of the Nevada Test Site and Tonopah Test Range will restore themselves through natural revegetation processes within a reasonable period of time.

Table 5. Vegetation recovery on Pahute Mesa plots initially disturbed by fallout debris in 1965.

	New seedlings and grass clumps on plot		
Plant species	1967	1970	1976
	Partially killed plot (100 × 100 m)		
Artemisia tridentata (80)[*]	35	390	1,170
Ceratoides lanata	5	5	5
Ephedra nevadensis	60	63	60
Grayia spinosa	20	28	55
Lycium andersonii	8	8	5
Mixed grasses	400	5,000	<5,000
	Totally killed plot (100 × 100 m)		
Artemisia tridentata (0)	111	2	62
Ceratoides lanata	2	4	6
Chrysothamnus nauseosus	1	3	21
Ephedra nevadensis	1	0	0
Grayia spinosa	15	25	34
Mixed grasses	500	5,000	<5,000
Salsola iberica	<7,000	2,000	< 500
Tetradymia axillaris	2	4	1
	Undisturbed control of plot (100 × 100 m)		
Artemisia tridentata (1,000)	6	14	65
Ephedra nevadensis	85	85	85
Grayia spinosa	14	14	14
Mixed grasses	100	80	120

[*] Values in parenthesis indicate number of original shrubs still living in plot as of September 1967. Each of the plots had about 1000 shrubs before disturbance, based upon dead shrub count.

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